Kineziologija 27 (1995) 1:62-72

INFLUENCE OF CYCLIC MONOSTRUCTURAL ACTIVITIES ON SOME BIOMECHANICAL, METABOLIC AND FUNCTIONAL CHARACTERISTICS IN ATHLETES

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Izvorni znanstveni članak
UDK: 796.012
Primljeno: 14.9.94.
Prihvaćeno: 2.3.95.

Abstract

Some quantitative characteristics of muscular fatigue and processes of muscular regeneration after two different specific running workloads were analysed on a sample of eight well-trained middle- and long-distance runners, with the use of a measuring procedure encompassing six biomechanic parameters of muscular function, one functional and one biochemical parameter.

The most important experimental findings are:

1. More intensive interval training load has resulted in a greater decrease (degree of fatigue) in those muscular contractile capacities which form the physiological basis of muscle strength and speed. A continuous 6 km long run at a speed of 4.96 m/s caused a larger deficiency in the parameters defining the basis of muscular endurance capacity.

2. The recovery of the force of muscle contraction (power) and biomechanical parameters of the speed of muscle contraction is rapid and takes 10-15 minutes, while the recovery of muscle endurance is a slower process and takes 1 to 2 hours, similar as the processes of lactate elimination from blood.

3. Supercompensation of muscular contraction characteristics (power and speed of contraction) is attained in 10 up to 15 minutes after the run and is further maintained at least 40 minutes after the exertion.

Key words: *running, muscular fatigue, biomechanics, training*

Sažetak

UTJECAJ CIKLIČKIH MONOSTRUKTURALNIH AKTIVNOSTI NA NEKE BIOMEHANIČKE, METABOLIČKE I FUNKCIONALNE KARAKTERISTIKE KOD ATLETIČARA

Neke kvantitativne karakteristike mišićnog umora i procesa mišićne regeneracije nakon dva različita opterećenja kod trčanja analizirane su na uzorku od osam dobro utreniranih trkača na srednje i duge pruge. Koristili smo se mjernim postupkom koji je obuhvaćao šest biomehaničkih parametara mišićne funkcije, jedan funkcionalan i jedan biokemijki parametar.

Najvažnija saznanja iz ovog istraživanja su:

1. Intenzivnije opterećenje kod intervalnog treniranja rezultiralo je većim smanjenjem (stupanj umora) onih mišićnih kontraktilnih sposobnosti koje tvore fiziološku osnovu mišićne snage i brzine. Kontinuirano trčanje na 6 km brzinom od 4.96 m/s uzrokovalo je veću deficijenciju kod parametara koji definiraju osnovu mišićne izdržljivosti.

2.Obnavljanje sile mišićne kontrakcije (jakost), te biomehaničkih parametara brzine mišićne kontrakcije je brzo i zahtijeva 10 do 15 minuta, dok je obnavljanje mišićne izdržljivosti dugotrajniji proces i zahtijeva 1 do 2 sata, slično kao i procesi eliminacije laktata iz krvi.

3. Superkompenzacija karakteristika mišićne kontrakcije (jakost

Zusammenfassung

DER EINFLUß VON ZYKLISCHEN MONOSTRUKTURELLEN AKTIVITÄTEN AUF EINIGE BIOMECHANISCHE, METABOLISCHE UND FUNKTIONELLE CHARAKTERISTIKEN BEI DEN LEICHTATHLETEN

Einige quantitative Charakteristiken der Muskelermüdung und des Prozesses der Muskelregeneration nach zwei verschiedenen Belastungen beim Laufen wurden auf dem Muster von acht gut trainierten Läufern beim Mittel- und Langstreckenlauf analysiert. Es wurde ein solches Meßverfahren angewendet, das sechs biomechanische Parameter der Muskelfunktion, einen funktionellen und einen biochemischen Parameter umfaßte.

Die wichtigsten Erkenntnisse aus diesem Artikel sind:

1. Das Resultat der höheren Belastung beim Intervaltraining war die wesentliche Erniedrigung (Ermüdungsstufe) von denjenigen muskulären Kontraktionsfähigkeiten, die die physiologische Basis der Muskelkraft und der Geschwindigkeit darstellen. Das kontinuierliche 6-km-Laufen (Geschwindigkeit 4.96 m/s) verursachte einen höheren Mangel bei den Parametern, die die Basis der Muskelausdauer definieren.

2. Die Wiedergewinnung von der Kraft der Muskelkontraktion (Kraft) und von den biomechanischen Parametern der Muskelkontraktionsgeschwindigkeit ist schnell und beträgt 10 bis 15 Minuten. Die Wiedergewinnung von Muskelausdauer *i brzina kontrakcije) postiže se za 10 do 15 minuta nakon trčanja i održava se najmanje daljnjih 40 minuta nakon napora.*

Ključne riječi: *trčanje, mišićni zamor, biomehanika, trening*

ist ein langfristigerer Prozeß und verlangt 1 bis 2 Stunden, ähnlich wie die Prozesse der Laktatenelimination aus dem Blut.

3. Die Suprakompensation von Charakteristiken der Muskelkontraktion (Kraft und Geschwindigkeit der Kontraktion) wird in 10 bis 15 Minuten nach dem Laufen erzielt, und wird mindestens die weiteren 40 Minuten nach der Anstrengung beibehalten.

Schlüsselwörter: *Laufen, Muskelermüdung, Biomechanik, Training*

I. INTRODUCTION

The methodology of controlling transformation processes in cyclic monostructural branches of sport is founded on the principle of adaption of individual organ systems, biochemical and biophysical characteristics (level of energy potentials, acid-base status, etc.) or sports performance of an individual as a whole.

Physiological and biochemical studies of the characteristics of muscle activities (Jakovljev, 1979; Platanov, 1981), on which the methodology of planning and execution of training cycles is based, show that the basic indicators which define the functional state in the organism or its individual systems, or sports performance as a whole, pass through four phases (Figure 1) during the process of a strenuous sports activity and after it:

- Phase of fatigue: the diminution in the level of performance of individual organ systems and of the whole sports performance;
- Recovery of the capacity of the organ systems (restoration of homeostasis in the organism);
- Supercompensation: raising the capacities over the level before the sports effort;
- Regression: lowering of the elevated capacities to the level before the effort

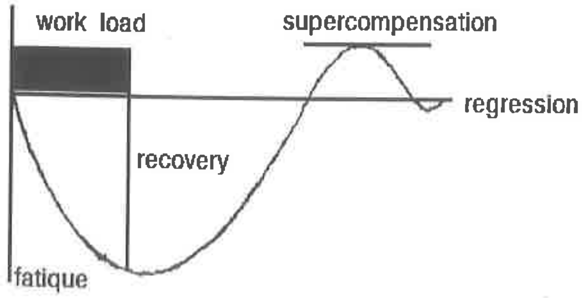


Figure 1: Performance phases during and after sports activity

The entire transformation process in endurance sports disciplines is directed towards an increase in performance of individual energy processes and a search for more rational methods of consumption of energy potentials. The basic task of the methodology concerning the formation of transformation processes in these sports is primarily to establish the optimum relationship between the workout methods with aerobic, aerobic-anaerobic, anaerobic-lactate and anaerobic-alactate effect as a function of the proportion or contribution of energy provided by a particular bioenergey system in the respective sports discipline.

Work loads of different contents and varying intensity produce amplitude changes that vary in size: a different degree of fatigue and differences in the duration of an individual phase in the recovery process. Efficient control of the transformation system in cyclic monostructural branches of sport requires adequate and accurate information on the characteristics, properties, influences and effects of various means and methods of workout which determine the degree of fatigue and the time and the course of the recovery process, the two foundations of the methodology of controlling transformation processes (Fohrenbach et al., 1987; Ratov and Krjazev, 1987). On the basis of the said information it is possible to formulate adequate modulation of the selected workout contents, rational distribution of work and rest in one exercise unit, in the microcycle, as well as in wider units of the training process.

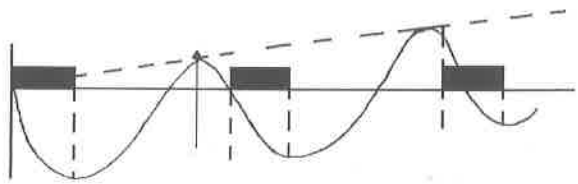


Figure 2: Optimal distribution of exercise loads ensures best performance of the training process

Only exact and completely individual (with respect to the actual abilities of the athlete) determination of optimum exercise load (suitably large work loads in individual exercise units and connection of these units at the right moment) ensures successfulness of the transformation process, which manifests itself in a progressive increase in the level of fitness (Figure 2).

Known are numerous studies, above all the study of Bigland-Ritchie with collaborators (1978, 1979, 1983) and Edwards with collaborators (1977, 1975) which on the basis of biomechanical changes deal profoundly with the issues of muscle fatigue in untrained individuals after non-specific workouts.

Given the fact that the manifestation of muscle fatigue depends on the type of work load, the extent and intensity of the work load, and also on the psychophysical abilities of the respective tested subjects (Jakovljev, 1982; Pahlke, 1991), it does not suffice to perform measurements under laboratory conditions, using nonspecific work loads on subjects selected at random, in order to gain realizations that could be used for the needs of sports practice.

In the literature, the issue of the recovery of the organism or muscle function after the effort is dealt with in a modest way, and often inadequately as regards the requirements of the methodology of sport training.

Recovery processes of the organism after sports effort are asynchronous and very complex (Platanov, 1981). Recovery of various functions of the organism take place in various ways and require time of a varying length.

The dynamics of the recovery of individual characteristics of muscle function, i.e. motor abilities (power, speed, endurance) varies with the intensity of the effort and requires different time periods to reach a new (higher) quality state.

The key issue of the methodology of sports training is how a particular characteristic of muscle function (motor ability) recovers after a particular effort. These realizations enable more efficient structuring of the training process where individual contents follow in an optimal sequence.

II. AIM

The purpose of the research was to find the quantitative characteristics of muscular fatigue after two different - from the viewpoint of metabolism - running workloads with the help of biomechanical, functional and biochemical parameters.

By monitoring muscular contraction in the pre-load state and at different time intervals after the workload we wanted to understand also the basic parameters of the processes of the regeneration of the muscular function.

III. METHODS

Test loads

Eight well trained long-distance and middle-distance runners carried out two different field tests:

- Continuous 6-km run at a speed of anaerobic threshold (criterion V_{OBLA}). The running speed was determined individually for every subject with respect to anaerobic threshold according to the Beaver's method (1985).
- Interval training of 5 x 300 meters at a submaximal speed with one-minute intermittent breaks. The speed of runs was determined for each subject on the basis of a 400-m test run.

The intensity of both run loads was accompanied by measurement of the pulse rate and the concentration of lactate in blood.

The pulse rate was measured by heart rate monitor PE 3000 (Polar Electro, Finland) and concentration of lactate in blood by Kontron 640 Lactate analiser.

Biomechanical parameters of the muscular contraction

1. Measurement procedure:

The force of an electrically stimulated muscle was measured in order to find the basic characteristics of fatigue of the peripheral muscular system after cyclic workloads of different intensity.

The muscle Vastus Lateralis was stimulated with a single supra-maximal 120 mA electric impulse. The impulse was of 0.3 ms duration. The electrodes for surface stimulation of muscles (Axelgaard, Fallbrook, CA) were placed on the distal and the middle part of the muscle. The posture of the subject during measurement and the placement of the electrodes are shown in picture 4.

The angle in the knee joint was 45 degrees. The torque in the knee during electrical stimulation was measured with a sensor (MES, Maribor) placed between the support hand and the frame of the table. The sensor signal was amplified and analysed with a personal computer. The electrical stimulator was of Slovenian origin (made at Faculty of Sport).

The analysis of the response of the muscle Vastus Lateralis to the electrical impulse (picture 3) was carried out through the following parameters:

1. The size of force of the stimulated muscle contraction - twitch (Fmax) (a.u.)**;

2. The time from the beginning of the increase of the muscle force up to the maximum contraction force (time to peak - TTP) (ms)*;

3. Half relaxation time of the stimulated muscle contraction (HRT) (ms);

4. The gradient of the muscle contraction force in the time to peak TTP (G_{TTP}) (a.u.);

5. The gradient of muscle relaxation in the HRT time (G_{HRT}) (a.u.)

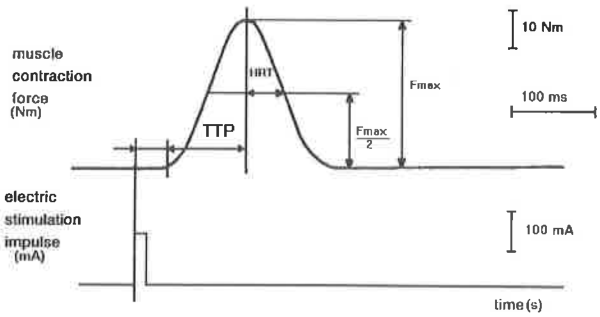


Figure 3: Force parameters and time parameters of muscle response (twitch) to a short electric impulse

2. Measurement procedure:

The force (FM3) was measured over a splint with a compression-tension instrument at the end of a 25-second maximal voluntary muscle contraction of the knee extensors.

The position of the subject during measurement is shown in Figure 4.

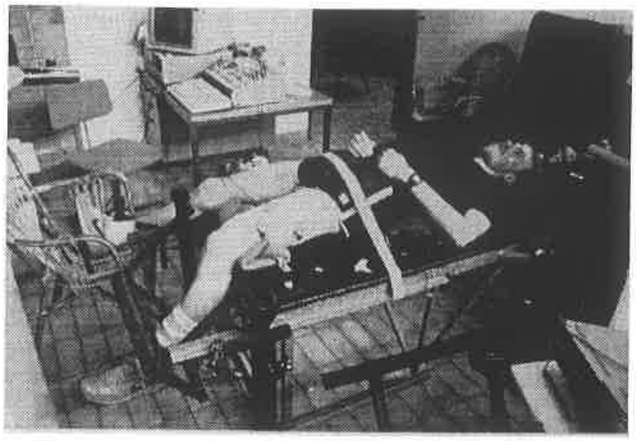


Figure 4: Position of the subject during measurement

Each subject was measured with a series of experimental procedures (functional-biochemical and biomechanical) in the state of resting, after warming up, i.e. preparation for the test load, and 8 times at different time intervals: 5, 10, 15, 20, 30, 40, 60, and 120 minutes after the termination of the effort.

In order to compare the states in different time-segments of the measurement procedure all parameters were relativised (given as relative values - percents - of the value measured before the workload).

Statistical methods

All results were related to the parameter value in the state of optimal preparation on the effort (after warming up), which was selected as a criterion value. Student's t-test was used to establish statistic significance between the results of individual parameters at differennt measurement points and between the results of parameters at different work loads.

IV. RESULTS AND DISCUSSION

1.Biochemical and functional parameters

The planned speed of a continuous 6-km long run with respect to the test results obtained on the treadmill amounted for the runners of the selected sample to 5.02 m/s ± 0.43, while the attained average speed was 4.96 m/sec. ± 0.29.

* milli second; ** arbitrary units

Despite the fact that the majority of subjects ran at a speed determined in the introductory testing by the OBLA-criterion, the concentration of lactate exceeded 4 mmol/l. After 3600 m of running, the average lactate concentration was between 5 and 5.5 mmol, and at the end of running it increased to 6.3 mmol/l (Figure 5).

From the kinetics of lactate during the effort we may conclude that in a long-lasting continuous run the running speed at VOBLA is the top limit of the steady state area of the lactate for the majority of the subjects in this sample. The reason for higher lactate concentration after a 6-km run lies undoubtedly also in the difference in the technique (running speed) between running on a treadmill and on the track.

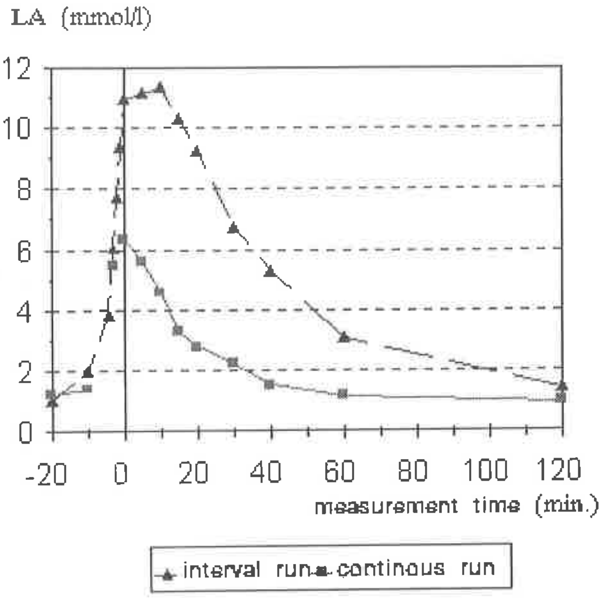
The planned and attained speed of interval runs 5 x 300 m at a submaximal speed with one-minute intermittent breaks amounted to 6.8 m/s * 0.4. The concentration of lactate in blood from one run to another increased linearly. With each next run, the lactate concentration increased by 2 mmol/l, and amounted at the termination of the work load to 11 mmol/l (Figure 5).

In both work loads, the frequency of heart beat approached maximal values (190 up to 195 heart beats per minute).

The concentration of lactate in blood increases slighlty for additional 10 minutes after the interval runs (it attains the value of 11.5 mmol/l), while after a long-distance run the concentration of lactate falls all the time. The kinetics of lactate concentration decrease in blood is similar in both load types. From the results it can be established that the halving time of lactate concentration in blood (i.e. the time in which the concentration of lactate falls off to 50 % of its highest value) is 30 - 40 minutes in the interval run, and 15 - 20 minutes in the continuous run. Two hours after the run, the concentraction of lactate falls to the level before the effort.

The processes of lactate elimination from blood after specific endurance training of various type lasted longer in all subjects of the selected sample than quoted by the sources in the literature. According to the data of Astrand (1986), the concentration of lactate in blood falls to the value before the effort after 60 minutes.

Hermansen and Vaage (1985) found that the major part of the lactate created in anaerobic metabolism is resynthetised in glycogen already in the muscle itself. These processes of regeneration of muscle glycogen depleted during sports activity take place



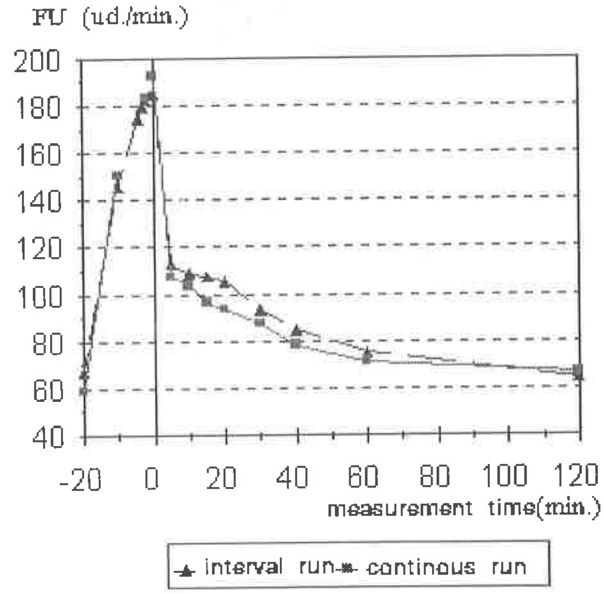


Figure 5: Kinetics of lactate and dynamics of heart rate before, during, and after different type of work load

relatively fast, in parallel with the elimination of lactate. Thus, 70 up to 80 % of muscle glycogen are restored already within 30 minutes after the termination of the effort.

Only a smaller part of lactate (up to 10 %) is conveyed from muscle cell into blood after the sports effort. This portion of lactate is broken down and neutralised in several ways in the time following the effort (buffer systems, consumption in the heart and kidneys, processes of glycogenesis in the liver, oxidation).

The kinetics of lactate concentration after different work loads shows clearly that the presence (intensity) and the duration of acidosis state in blood and muscle varies with the type of work load. Despite the fact that pH-values were not measured, it can be established from the lactate kinetics that the state of acidosis in blood after the interval runs is still present for 20 up to 25 minutes (LA after 25 minutes is 6.5 mmol/l). A reliable estimate of the level and duration of acidosis state after continuous running cannot be given on the basis of the lactate concentration in blood since the concentration of lactate at the end of effort attains 6.3 mmol/l which is on the limit of acidosis state.

The values of the heart rate at individual measurement points after different kinds of work loads (the levels after the effort being very similar) are very similar although the pulse frequency after the interval, that is, lactate anaerobic effort is slighlty higher. A pronounced fall of heart beat (from 190 down to 105-110) occurs in the first five minutes after the effort, and is then followed by a period of very mild calming down of the heart function. Yet, even 2 hours after the effort, the heart rate, and thus also aerobic processes (O2 consumption), is higher than in the state of resting.

2. Influence of various types of work load on various biomechanical parameters

Changed (deteriorated) contractile characteristics are the basic characteristic of muscle fatigue.

The results show that in biomechanical parameters which define power and speed of muscle contraction, anaerobic lactate interval training has proven - in comparison with 6-km continuous running under predominant aerobic conditions - to be the work load which causes greater deterioration in the contraction capacities of the muscular system - and thereby a higher degree of local muscle fatigue -, while continuous aerobic running causes a more pronounced fall in the capacity of voluntary (conscious) sustained muscle contraction (Table 1).

Table 1: The differences (AS ±SD) in biomechanical parameters before and after the work loads of various kind, and the statistical significance of the differences in the individual parameters between interval and continuous running

Parameter	Difference in %	P
Load type	P	
Continuous run	-13.5 ± 16.6	NS
Fmax	P=0.111	
Interval runs	-23.4 ± 11.2	**
Continuous run	-6.6 ± 6.8	*
TTP	P=0.852	
Interval runs	-6.9 ± 8.1	*
Continuous run	-6.8 ± 15.6	NS
HRT	P=0.151	
Interval runs	4.8 ± 14.7	NS
Continuous run	-7.2 ± 17.9	NS
G_{TTP}	P=0.209	
Interval runs	-17 ± 15.1	*
Continuous run	-4.5 ± 26.6	NS
G_{HRT}	P=0.021*	
Interval runs	-25.8 ± 14.5	**
Continuous run	-7.6 21.4	NS
F_{M3}	P= 0.239	
Interval runs	-13.7 ± 12	*

NS non significance

* $P< 0.05$

** $P< 0.01$

The most important reasons for reduction in the performance of the muscular contractile system (power and speed) are three interrelated mechanisms (Gibson and Edwards, 1985; Hermansen, 1981; Sahlin and Ren, 1986; Bigland-Ritchie et al., 1978, 1979; Jones, 1981; Jones et al. 1979):

1. Decrease in energy reserve of the muscle (above all CrP);

2.Insufficient and disturbed metabolic processes of regeneration of ATP and CrP under conditions of high acidosis;

3.Contraction processes are strongly slowed down due to changed ionic concentration.

Despite the obvious diminution of energy stores of phosphagens (ATP and primarily CrP) during continuous and interval running (they begin to be tapped already at 50 % V02 max (Hermansen, 1981), and according to the data of Harris, 1977, they are depleted in the processes of hydrolysis by 10 up to 30 %), a lower energy level in the muscle is in all probability not the most important cause either of the reduction in the contraction force of the electrically stimulated muscle, or of the change in the time parameters of muscle contraction. The reserves of ATP as the energy for a single muscle contraction triggered by electric impulse do not get exhausted to such an extent as to represent a significant disturbance for the muscular contraction performance.

The mechanisms of the neuromuscular junction and the various mechanisms taking part in the excitation-contraction combination have a much more important influence on the changed characteristics of the response of a tired muscle to electrical stimulus: the conductance of the membrane of a muscle cell and the processes in direct actomyosin formation (Stokes et al., 1989; Dachetau and Hainaut, 1985; Edwards et al., 1977; Kirkendall, 1990).

Each individaul mechanism has a different meaning in the explanation of muscle fatigue which depends on the type, above all on the intensity of the work load. During cyclic monostructural work of a long duration, the frequency of activating the motor units is from 10 to 20 Hz (Grimby and Honners, 1981; Edwards et al., 1977). With respect to this fact and to the realization that at low frequencies of activation of the motor units, more significant disturbances in the conductive performance of nerve pathways or motor end-plate (this is the characteristic of muscle activation at high frequencies, Gibson and Edwards, 1985; Jones, 1981; Jones et al. 1979; Bigland Ritchie et al. 1979), it seems that for the fall of the muscular contraction force and the change in the time parameters of muscle contraction, the mechanisms of excitation-contraction are accountable to the largest extent. The disturbances in this part of the contractile system are called low-frequency fatigue.

It can be assumed that for muscle fatigue (fall of strength performance and speed of muscle contraction) the same mechanisms are accountable both after interval runs as well as after continuous 6-km runs. The difference in the state of biomechanical parameters after different work loads is probably in that due to higher acidosis (concentration of lactate in blood), the influence of these mechanisms on the state of muscle function after different work loads is different.

The decrease in the electrically stimulated contraction force after cyclic loading can be explained from two aspects:

a) The activation aspect

Lower contraction force of a muscle after the run is the result of the inhibition of a definite number of active places of the contractile protein structures of actin and myosin. A high concentration of H+ -ions (acidosis) inhibits the activity of a certain part of cross bridges and produces thereby the decrease in the contraction force of muscle (Stryer, 1991; Kirkendall, 1990).

Elevated acidosis in a muscle weakens the function of Na+ - K+ of ATPase. The change in the performance of this enzyme brings about a change in the intramuscular ionic concentration and thereby the weakening of the propagation of the action potential along the muscle fiber. The consequence is a smaller number of activated sarkomeres (Dachetau and Hainaut, 1985; Sahlin and Ren, 1986; Sahlin, 1986) and a weaker muscle contraction.

b) The topological aspect

The fall of muscular contraction force after the run can also be explained by the raise of the excitation threshold of the individual motor units: probably of those which were subjected to the heaviest load during running. It is possible that the current of the electrical impulse at which the stimulation of a fresh muscle was carried out does not succeed to activate tired motor units in the tired muscle, which means a smaller contraction force.

The question which arises here is which muscle fibers, i.e. motor units carry the major load in different run workouts.

The question is justified also in view of the fact that after the run, the contraction time of the muscle shortened, while the relaxation time increased only in certain cases as was expected with respect to the results in the literature.

It is possible that in the effort at a running speed from 5 to 6.6 m/s, slow muscle fibers (PV and HOV) are more active; they get tired during long running and do not react to electrical stimulus after the run owing to a higher excitation threshold. However, those muscle fibers - motor units which were not (or were less) active during the effort do react. These are above all fast muscle fibers (HOGV). With respect to the structure of the selected sample, which was for the most part represented by middle-distance and long-distance runners, it can be expected that the proportion of fast muscle structure in them is rather modest and therefore the contraction force of the muscle after the effort is smaller, yet faster. The contraction time TTP decreases after both types of work loads by the same amount, i.e. by approx. 7 %.

In the perception of muscular fatigue, the contraction time is a very insensitive parameter. Slower muscle contraction was caused only by really exhausting loading (pronouncedly high acidosis or high concentration of lactate in blood).

One of the basic characteristics of muscle fatigue is slower relaxation. The increase in the HTT-time was established in those runners in whom interval run loads caused exhaustion (a much larger level of acidosis). The speed of muscle relaxation depends primarily on the speed of the transport (operation of the calcium pump) of Ca++ ions (pumping back into tubular reservoirs after relaxation which triggers muscular contraction).

Raised concentration of Ca++ ions in protein muscle structures, which is the result of high acidosis and the related worse performance of the calcium pump, reduces the speed of dissociation of cross-bridges and extends thereby the time of muscle relaxation.

The fall in effective maintenance of maximal isometric contraction (F_{M3}), as the criterion of endurance capacity of a muscle, is larger after long continuous effort than after a more intensive, yet shorter one. The basic reason lies in larger depletion of glycogen stores in the muscle during a more sustained effort.

3. The dynamics of recovery of biomechanical parameters

a) The dynamics of recovery of stimulated and voluntary muscle force

The contraction force of a muscle decreased with respect to the state before the effort by 13,5 16.6 %, and after more intensive interval runs by 23,4 11.2 %. After a pronounced fall in muscle force produced by a strenuous interval or continuous run, the twitch force attains already in the 10th minute after the effort the values that are 13.5 23 % or 14.1 16.3 % higher (supercompensation level) than those before the effort (fresh muscle after warming up).

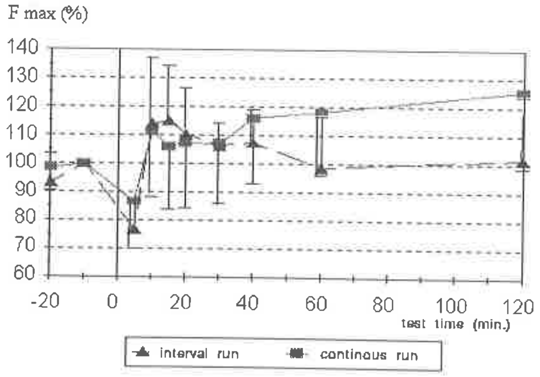


Figure 6: The influence of different type of work load on the twitch force (Fmax) and the force of voluntary muscle contraction F_{M3} and the dynamics of their recovery

After a continuous effort, F_{M3} is 13.7 2 % lower than the force before the effort, while an interval effort produces only a 7.6 21.4 % decrease in the isometric force. One hour after the effort, the level of the voluntary muscle force is still 8.2 22 % or 10.3 15.5 % below the initial state. It approximates the state before the effort not earlier than after two hours.

The processes of recovery of the contraction capacity of muscle can be dealt with from the energy and topological aspect.

a) The energy aspect

The dynamics of the recovery of the twitch force after various types of work loads does not confirm in our research entirely the known foreign findings concerning the measurements of the muscular contraction force. According to the data of Cooper et al. (1988), Duchetau and Hainaut (1985), the recovery of muscular contraction force after 60 seconds of isometric or dynamic loading under laboratory conditions takes only 4 up to 5 minutes.

However, the findings of our research show that after specific endurance exercise units, the processes of recovery begin not earlier than about the fifth minute after the effort and attain their full development 10 to 15 minutes after the exercise unit has been completed.

Under the conditions of high acidosis resultant primarily from interval but also from continuous sustained efforts, the time of recovery of energy complexes and other processes which affect decisively the contraction of a muscle is obviously extended. A high concentration of lactate in a muscle cell after the effort does not block recovery processes, but only weakens and slows them down.

The characteristic of the recovery of the voluntary muscle force F_{M3} in comparison with that of the electrically stimulated muscle force Fmax is a slower course of recovery and very small amplitudes of changes in the size of the said parameter at individual measurement points. Without doubt, the reduction in glycogen capacity after a long-lasting run, i.e. slower processes of replenishing the reserves, has also influence on a slower recovery of the capacity of sustained muscle contraction.

b) The topological aspect

The structure of each muscle is specific and versatile in respect to the characteristic properties of muscle fibers. Their structure varies in different athletes and depends on the type of activity they are engaged in.

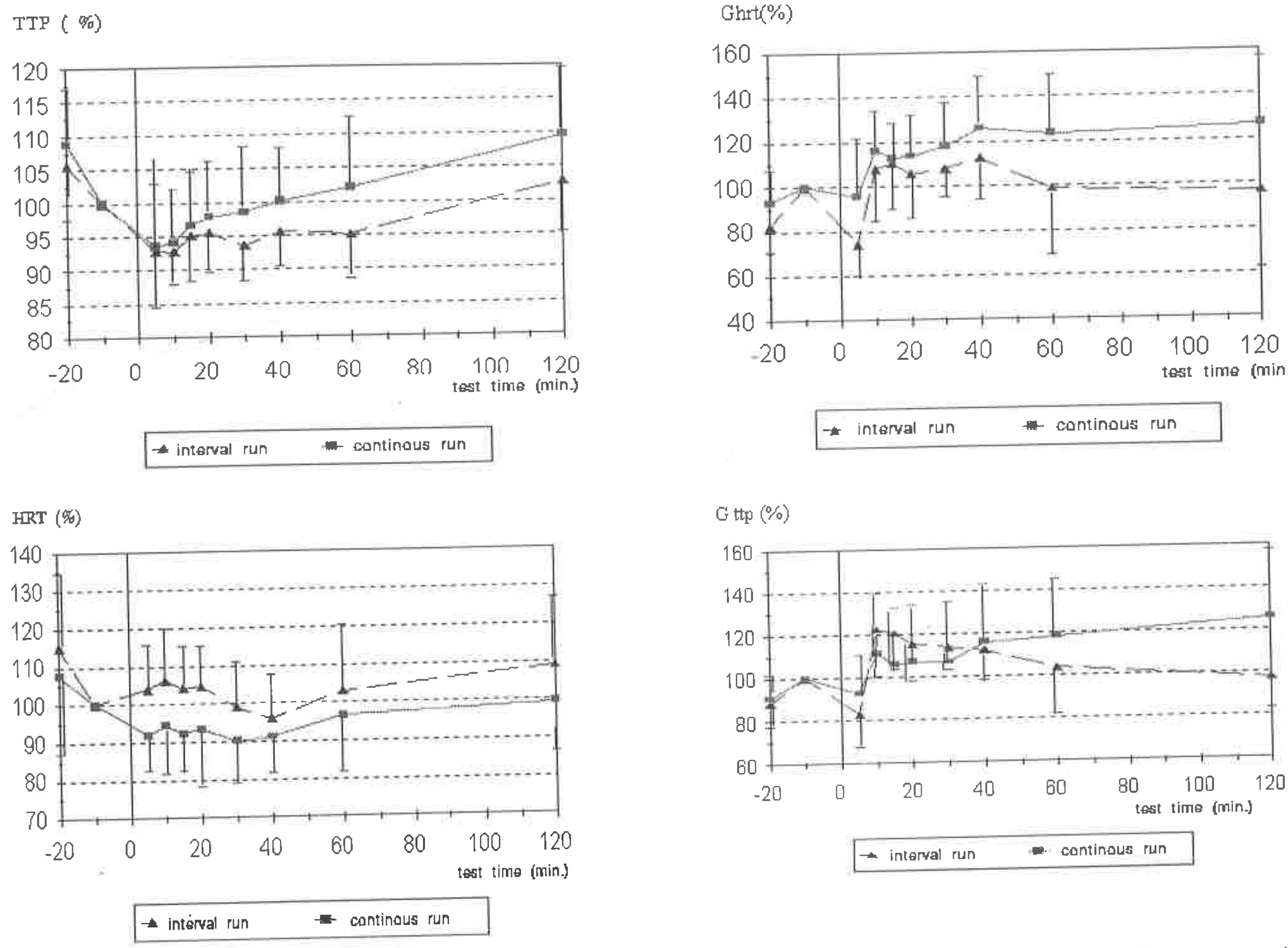


Figure 7: Influence of work loads of different type on the time of muscle contraction and relaxation, gradient G_{TTP} and G_{HRT}, and the dynamics of recovery of these parameters

Sahlin and Ren (1989) found that after a high-intensity effort the concentration of lactate in fast muscle fibers is even 60 % higher than in the slow ones. There is a possibility that under aerobic conditions after the effort, lactate and other metabolites pass from the more into less active muscle fibers. In this way, the functional conditions of the muscle structures that are active during the effort improve which can be manifested also in a higher contraction force. The theory on the rearrangement of metabolites in a muscle can also be used to explain the differences in the intensity of the dynamics of recovery processes after the first and after the second type of effort.

From the aspect of metabolism (lactate quantity), the interval run is more intensive, therefore the process of removing the metabolic products in the initial stage of recovery is much more lively, while in the state of stabilization of the internal muscle environment these processes become much more calm.

b) The dynamics of recovery of the time parameters in muscle contraction after different work loads

The TTP-time shortens after both effort types by 6 ms or by 6.9 8.1 % (6.6 %), while afterwards it increases during the whole time of the experiment.

The relationship between the size of the force Fmax and the TTP-time decreases after the interval run by 17.5 15.1 %, and after the continuous run by 7.2 17.9 %; however, already after 10 minutes of break the value of this parameter is considerably higher than before the effort (Figure 7).

The HRT-time increases after intensive anaerobic work, while after continuous aerobic work muscle relaxation becomes faster (Figure 7).

The dynamics of changing of the time parameters of muscle contraction (speed of muscle contraction) in the period two hours after the run differs considerably from the course of recovery of muscular contraction force.

Faster restoration (increase) of the contraction time to the value before the effort is present after a long continuous effort. This difference can be the result of a faster recovery of the motor units loaded during running (slower motor units). Once these slow motor units have recovered and become fully active, the contraction time increases, but at the same time the contraction force Fmax also increases. After more intensive interval runs, the processes of reactivation of the motor units that got tired during running are longer. The slowing down of these processes is also affected by the level and duration of the acidosis state.

The largest differences between continuous long-lasting and interval efforts are seen in the influence on the half relaxation time (HRT). Aerobic load causes the shortening of the time of muscle relaxation, while anaerobic lactate load causes the extension of this time parameter. It is possible that the elevated state of acidosis, which is after the interval runs still present for additional 20 to 25 minutes, affects adversely the performance of the calcium pump. This means slower pumping back of Ca^{++} ions into tubular reservoirs, which results in a slower dissociation of actomyosin complexes and a longer time of muscle relaxation.

V. THE IMPORTANCE OF RESEARCH FINDINGS FOR THE METHODOLOGY OF SPORTS TRAINING IN MONOSTRUCTURAL CYCLIC BRANCHES OF SPORT

On the basis of the results of this study it can be summarised that after intensive, yet unexhausting specific cyclic monostructural effort, the recovery of muscle force and speed of muscle contraction and relaxation, which builds the physiological basis of muscle force and speed, is completed already after 10 to 15 minutes (in this time it also attains the supercompensation level), and that the muscular contraction capacity remains on a higher level than the initial (pre-effort) one at least for additional 40 minutes after the effort.

These realizations offer several possibilities in devising individual exercise units in the process of sport training in endurance disciplines.

With respect to the results of the study it wasreasonable to insert the elements of speed, explosive power or exercise units of short-lasting speed endurance between long aerobic workouts or at the end of aerobic or anaerobic lactate exercise units. In these cases there should be 10 up to 15 minutes of break before the begin of speed training in order to allow the muscular system to attain its highest level. It is reasonable to often include the elements of speed and power training in the process of endurance training.

With such training organization, an increase in the performance of speed - power training -and at the increased total scope of training also the performance of basic endurance training -, can be expected.

In the state of elevated (maximal) peripheral muscular function it is possible to expect that the competitive performance (at least in shorter disciplines, where a certain muscle tone is required: 400 m, 800m, 1500m) will also be more successful.

A longer or shorter intensive, yet not exhausting activity in the duration of 15 to 30 minutes before competition activates the neuromuscular system so that at the begin of competition it is in the best condition.

In practice there are known numerous cases of inclusion of various exercises immediately before competition. This thesis is also supported by the experiences gained in competitions when competitors perform very succesfully in a short time (30 minutes or even less) two times (800 m, relay race 4 x 400 m, or two times in the same discipline).

Such thinking is also confirmed by the results in the chapter dealing with the effects of warming up and the influence of preparatory - prestart activities on the performance of muscular function. These results open the question which contents and in what extent should be used, and above all, how intensive should be the activities of warming up in order to attain the highest competitive performance of an athlete. However, these aspects were not the object of this research.

The results of the research open indirectly, and at the same also answer the question concerning the contents, scope and above all the intensity of prestart activities, i.e. warming up. On the basis of the previous findings and some measurements included in this research it shows clearly that warming up which activates functional, metabolic and other functions to a level required by competitive activity is more efficient than less intensive preparation for workout or competition race.

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